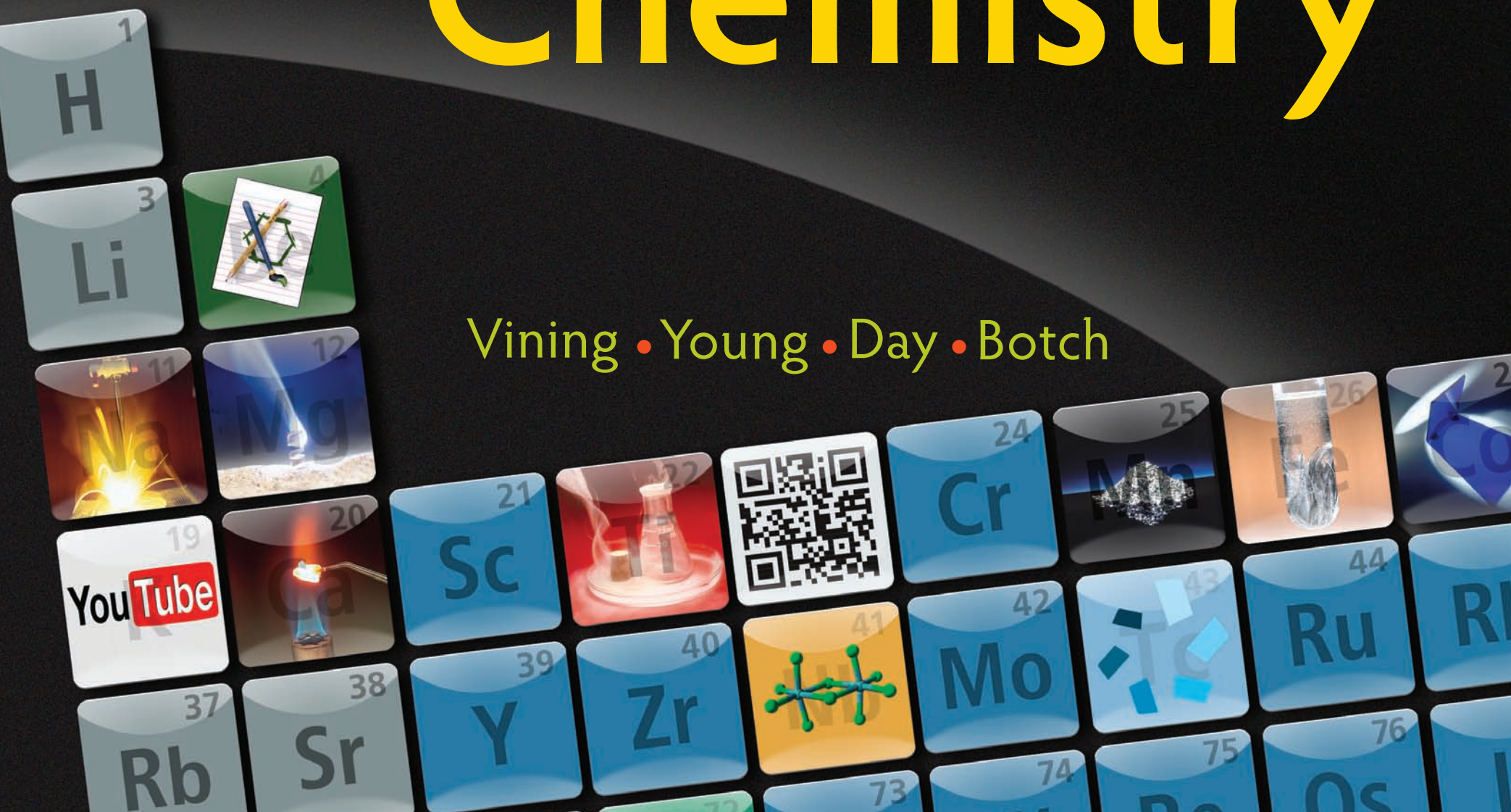


General Chemistry

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1 2 3 4 5 6 7 18 17 16 15 14

Contents

1 Chemistry: Matter on the Atomic Scale 1

1.1	What Is Chemistry?	2
1.1a	The Scale of Chemistry	2
1.1b	Measuring Matter	2
1.2	Classification of Matter	3
1.2a	Classifying Matter on the Atomic Scale	3
1.2b	Classifying Pure Substances on the Macroscopic Scale	5
1.2c	Classifying Mixtures on the Macroscopic Scale	8
1.3	Units and Measurement	10
1.3a	Scientific Units and Scientific Notation	10
1.3b	SI Base Units and Derived Units	12
1.3c	Significant Figures, Precision, and Accuracy	15
1.4	Unit Conversions	19
1.4a	Dimensional Analysis	19
1.4b	Unit Conversions Using Density	21
	Unit Recap	23

2 Elements and Compounds 27

2.1	The Structure of the Atom	28
2.1a	Components of an Atom	28
2.1b	Atomic Number, Mass Number, and Atomic Symbols	29
2.1c	Isotopes and Atomic Weight	30
2.2	Elements and the Periodic Table	33
2.2a	Introduction to the Periodic Table	33
2.3	Covalent Compounds	37
2.3a	Introduction to Covalent Compounds	37
2.3b	Representing Covalent Compounds with Molecular and Empirical Formulas	37
2.3c	Representing Covalent Compounds with Molecular Models	40
2.3d	Naming Covalent Compounds	41
2.4	Ions and Ionic Compounds	44
2.4a	Monoatomic Ions	44
2.4b	Polyatomic Ions	47
2.4c	Representing Ionic Compounds with Formulas	47
2.4d	Naming Ionic Compounds	49
2.4e	Identifying Covalent and Ionic Compounds	50
	Unit Recap	51

3	Stoichiometry	55
3.1	The Mole and Molar Mass	56
3.1a	Avogadro's Number	56
3.1b	Molar Mass	57
3.2	Stoichiometry and Compound Formulas	60
3.2a	Element Composition	60
3.2b	Percent Composition	62
3.2c	Empirical Formulas from Percent Composition	63
3.2d	Determining Molecular Formulas	65
3.2e	Hydrated Compounds	67
3.3	Stoichiometry and Chemical Reactions	69
3.3a	Chemical Reactions and Chemical Equations	69
3.3b	Balancing Chemical Equations	71
3.3c	Reaction Stoichiometry	74
3.4	Stoichiometry and Limiting Reactants	79
3.4a	Limiting Reactants	79
3.4b	Percent Yield	82
3.5	Chemical Analysis	84
3.5a	Determining a Chemical Formula	84
3.5b	Analysis of a Mixture	89
	Unit Recap	90

4	Chemical Reactions and Solution Stoichiometry	93
4.1	Types of Chemical Reactions	94
4.1a	Combination and Decomposition Reactions	94
4.1b	Displacement Reactions	95
4.2	Aqueous Solutions	97
4.2a	Compounds in Aqueous Solutions	97
4.2b	Solubility of Ionic Compounds	99
4.3	Reactions in Aqueous Solution	101
4.3a	Precipitation Reactions and Net Ionic Equations	101
4.3b	Acid–Base Reactions	104
4.3c	Gas-Forming Reactions	108
4.4	Oxidation–Reduction Reactions	110
4.4a	Oxidation and Reduction	110
4.4b	Oxidation Numbers and Oxidation States	111
4.4c	Recognizing Oxidation–Reduction Reactions	113
4.5	Stoichiometry of Reactions in Aqueous Solution	115
4.5a	Solution Concentration and Molarity	115
4.5b	Preparing Solutions of Known Concentration	118
4.5c	Solution Stoichiometry	122
4.5d	Titrations (Part 1)	124
4.5e	Titrations (Part 2)	128
	Unit Recap	130

5	Thermochemistry	135
5.1	Energy	136
5.1a	Kinetic and Potential Energy	136
5.1b	Measuring Energy: Energy Units	137
5.1c	Principles of Thermodynamics	138
5.2	Enthalpy	140
5.2a	Enthalpy	140
5.2b	Representing Energy Change	142
5.3	Energy, Temperature Changes, and Changes of State	143
5.3a	Heat Transfer and Temperature Changes: Specific Heat Capacity	143
5.3b	Heat Transfer Between Substances: Thermal Equilibrium and Temperature Changes	146
5.3c	Energy, Changes of State, and Heating Curves	148
5.4	Enthalpy Changes and Chemical Reactions	152
5.4a	Enthalpy Change for a Reaction	152
5.4b	Enthalpy Change and Chemical Equations	153
5.4c	Constant-Pressure Calorimetry	155
5.4d	Constant-Volume Calorimetry	157
5.5	Hess's Law	159
5.5a	Hess's Law	159
5.6	Standard Heats of Reaction	161
5.6a	Standard Heat of Formation	161
5.6b	Using Standard Heats of Formation	165
	Unit Recap	167

6	Electromagnetic Radiation and the Electronic Structure of the Atom	171
6.1	Electromagnetic Radiation	172
6.1a	Wavelength and Frequency	172
6.1b	The Electromagnetic Spectrum	173
6.2	Photons and Photon Energy	174
6.2a	The Photoelectric Effect	174
6.3	Atomic Line Spectra and the Bohr Model of Atomic Structure	176
6.3a	Atomic Line Spectra	176
6.3b	The Bohr Model	177
6.4	Quantum Theory of Atomic Structure	180
6.4a	Wave Properties of Matter	180
6.4b	The Schrödinger Equation and Wave Functions	182
6.5	Quantum Numbers, Orbitals, and Nodes	183
6.5a	Quantum Numbers	183
6.5b	Orbital Shapes	184
6.5c	Nodes	187
6.5d	Orbital Energy Diagrams and Changes in Electronic State	187
	Unit Recap	189

7 Electron Configurations and the Properties of Atoms 193

7.1	Electron Spin and Magnetism	194
7.1a	Electron Spin and the Spin Quantum Number, m_s	194
7.1b	Types of Magnetic Materials	194
7.2	Orbital Energy	196
7.2a	Orbital Energies in Single- and Multielectron Species	196
7.3	Electron Configuration of Elements	196
7.3a	The Pauli Exclusion Principle	196
7.3b	Electron Configurations for Elements in Periods 1–3	198
7.3c	Electron Configurations for Elements in Periods 4–7	201
7.3d	Electron Configurations and the Periodic Table	205
7.4	Properties of Atoms	207
7.4a	Trends in Orbital Energies	207
7.4b	Atomic Size	209
7.4c	Ionization Energy	211
7.4d	Electron Affinity	212
7.5	Formation and Electron Configuration of Ions	213
7.5a	Cations	213
7.5b	Anions	217
7.5c	Ion Size	219
Unit Recap		222

8 Covalent Bonding and Molecular Structure 225

8.1	An Introduction to Covalent Bonding	226
8.1a	Coulomb's Law	226
8.1b	Fundamentals of Covalent Bonding	227
8.2	Lewis Structures	228
8.2a	Lewis Symbols and Lewis Structures	228
8.2b	Drawing Lewis Structures	231
8.2c	Exceptions to the Octet Rule	234
8.2d	Resonance Structures	236
8.3	Bond Properties	238
8.3a	Bond Order, Bond Length, and Bond Energy	238
8.3b	Resonance Structures, Bond Order, Bond Length, and Bond Energy	242
8.3c	Bond Energy and Enthalpy of Reaction	244
8.4	Electron Distribution in Molecules	245
8.4a	Formal Charge	245
8.4b	Bond Polarity	247
8.4c	Resonance Structures, Formal Charge, and Electronegativity	249
8.5	Valence-Shell Electron-Pair Repulsion Theory and Molecular Shape	253
8.5a	VSEPR and Electron-Pair Geometry	253
8.5b	Shape (Molecular Geometry)	256
8.6	Molecular Polarity	259
8.6a	Molecular Polarity	259
Unit Recap		262

9	Theories of Chemical Bonding	265
9.1	Valence Bond Theory	266
9.1a	Tenets of Valence Bond Theory	266
9.2	Hybrid Orbitals	267
9.2a	sp^3 Hybrid Orbitals	267
9.2b	sp^2 Hybrid Orbitals	269
9.2c	sp Hybrid Orbitals	270
9.2d	sp^3d Hybrid Orbitals	272
9.2e	sp^3d^2 Hybrid Orbitals	274
9.3	Pi Bonding	276
9.3a	Formation of Pi Bonds	276
9.3b	Pi Bonding in Ethene, C_2H_4 , Acetylene, C_2H_2 , and Allene, CH_2CCH_2	277
9.3c	Pi Bonding in Benzene, C_6H_6	279
9.3d	Conformations and Isomers	281
9.4	Molecular Orbital Theory	283
9.4a	Sigma Bonding and Antibonding Molecular Orbitals	283
9.4b	Pi Bonding and Antibonding Molecular Orbitals	284
9.4c	Molecular Orbital Diagrams (H_2 and He_2)	284
9.4d	Molecular Orbital Diagrams (Li_2-F_2)	285
9.4e	Molecular Orbital Diagrams (Heteronuclear Diatomics)	289
9.4f	Molecular Orbital Diagrams (More Complex Molecules)	289
	Unit Recap	290

10	Gases	293
10.1	Properties of Gases	294
10.1a	Overview of Properties of Gases	294
10.1b	Pressure	295
10.2	Historical Gas Laws	297
10.2a	Boyle's Law: $P \times V = k_B$	297
10.2b	Charles's Law: $V = k_C \times T$	298
10.2c	Avogadro's Law: $V = k_A \times n$	300
10.3	The Combined and Ideal Gas Laws	302
10.3a	The Combined Gas Law	302
10.3b	The Ideal Gas Law	303
10.3c	The Ideal Gas Law, Molar Mass, and Density	304
10.4	Partial Pressure and Gas Law Stoichiometry	307
10.4a	Introduction to Dalton's Law of Partial Pressures	307
10.4b	Partial Pressure and Mole Fractions of Gases	309
10.4c	Gas Laws and Stoichiometry	310
10.5	Kinetic Molecular Theory	312
10.5a	Kinetic Molecular Theory and the Gas Laws	312
10.5b	Molecular Speed, Mass, and Temperature	314
10.5c	Gas Diffusion and Effusion	317
10.5d	Nonideal Gases	319
	Unit Recap	322

11	Intermolecular Forces and the Liquid State	325
11.1	Kinetic Molecular Theory, States of Matter, and Phase Changes	326
11.1a	Condensed Phases and Intermolecular Forces	326
11.1b	Phase Changes	328
11.1c	Enthalpy of Vaporization	329
11.2	Vapor Pressure	330
11.2a	Dynamic Equilibrium and Vapor Pressure	330
11.2b	Effect of Temperature and Intermolecular Forces on Vapor Pressure	332
11.2c	Boiling Point	335
11.2d	Mathematical Relationship between Vapor Pressure and Temperature	338
11.3	Other Properties of Liquids	340
11.3a	Surface Tension	340
11.3b	Viscosity	342
11.3c	Capillary Action	342
11.4	The Nature of Intermolecular Forces	343
11.4a	Dipole–Dipole Intermolecular Forces	343
11.4b	Dipole–Induced Dipole Forces	345
11.4c	Induced Dipole–Induced Dipole Forces	346
11.5	Intermolecular Forces and the Properties of Liquids	347
11.5a	Effect of Polarizability on Physical Properties	347
11.5b	Effect of Hydrogen Bonding on Physical Properties	348
11.5c	Quantitative Comparison of Intermolecular Forces	350
	Unit Recap	353

12	The Solid State	357
12.1	Introduction to Solids	358
12.1a	Types of Solids	358
12.1b	The Unit Cell	359
12.2	Metallic Solids	362
12.2a	Simple Cubic Unit Cell	362
12.2b	Body-Centered Cubic Structure	363
12.2c	Closest-Packed Structure	364
12.2d	X-ray Diffraction	368
12.3	Ionic Solids	370
12.3a	Holes in Cubic Unit Cells	370
12.3b	Cesium Chloride and Sodium Chloride Structures	374
12.3c	Zinc Blende (ZnS) Structure	377
12.3d	Complex Solids	378
12.4	Bonding in Metallic and Ionic Solids	380
12.4a	Band Theory	380
12.4b	Lattice Energy and Born–Haber Cycles	382
12.5	Phase Diagrams	385
12.5a	Phase Changes Involving Solids	385
12.5b	Phase Diagrams	386
	Unit Recap	392

13	Chemical Mixtures: Solutions and Other Mixtures	397
13.1	Quantitative Expressions of Concentration	398
13.1a	Review of Solubility	398
13.1b	Concentration Units	399
13.2	Inherent Control of Solubility	403
13.2a	Entropy and Thermodynamic Control of Chemical Processes	403
13.2b	Gas–Gas Mixtures	405
13.2c	Liquid–Liquid Mixtures	407
13.2d	Solid–Liquid Mixtures	409
13.3	External Control of Solubility	412
13.3a	Pressure Effects: Solubility of Gases in Liquids	412
13.3b	Effect of Temperature on Solubility	414
13.4	Colligative Properties	416
13.4a	Osmotic Pressure	416
13.4b	Vapor Pressure Lowering	421
13.4c	Boiling Point Elevation	423
13.4d	Freezing Point Depression	425
13.5	Other Types of Mixtures	427
13.5a	Alloys	427
13.5b	Colloids	428
	Unit Recap	431

14	Chemical Kinetics	435
14.1	Introduction to Kinetics	436
14.1a	Factors that Influence Reactivity	436
14.1b	Collision Theory	437
14.2	Expressing the Rate of a Reaction	439
14.2a	Average Rate and Reaction Stoichiometry	439
14.2b	Instantaneous and Initial Rates	442
14.3	Rate Laws	442
14.3a	Concentration and Reaction Rate	442
14.3b	Determining Rate Law Using the Method of Initial Rates	445
14.4	Concentration Change over Time	448
14.4a	Integrated Rate Laws	448
14.4b	Graphical Determination of Reaction Order	452
14.4c	Reaction Half-Life	455
14.4d	Radioactive Decay	457
14.5	Activation Energy and Temperature	458
14.5a	Reaction Coordinate Diagrams	458
14.5b	The Arrhenius Equation	463
14.5c	Graphical Determination of E_a	465
14.6	Reaction Mechanisms and Catalysis	466
14.6a	The Components of a Reaction Mechanism	466
14.6b	Multistep Mechanisms	469
14.6c	Reaction Mechanisms and the Rate Law	472
14.6d	More Complex Mechanisms	474
14.6e	Catalysis	477
	Unit Recap	479

15	Chemical Equilibrium	483
15.1	The Nature of the Equilibrium State	484
15.1a	Principle of Microscopic Reversibility	484
15.1b	The Equilibrium State	485
15.2	The Equilibrium Constant, K	487
15.2a	Equilibrium Constants	487
15.2b	Writing Equilibrium Constant Expressions	489
15.2c	Manipulating Equilibrium Constant Expressions	492
15.3	Using Equilibrium Constants in Calculations	495
15.3a	Determining an Equilibrium Constant Using Experimental Data	495
15.3b	Determining Whether a System Is at Equilibrium	497
15.3c	Calculating Equilibrium Concentrations	499
15.4	Disturbing a Chemical Equilibrium: Le Chatelier's Principle	501
15.4a	Addition or Removal of a Reactant or Product	501
15.4b	Change in the Volume of the System	504
15.4c	Change in Temperature	506
	Unit Recap	509

16	Acids and Bases	513
16.1	Introduction to Acids and Bases	514
16.1a	Acid and Base Definitions	514
16.1b	Simple Brønsted–Lowry Acids and Bases	515
16.1c	More Complex Acids	517
16.2	Water and the pH Scale	518
16.2a	Autoionization	518
16.2b	pH and pOH Calculations	522
16.3	Acid and Base Strength	524
16.3a	Acid and Base Hydrolysis Equilibria, K_a , and K_b	524
16.3b	K_a and K_b Values and the Relationship Between K_a and K_b	527
16.3c	Determining K_a and K_b Values in the Laboratory	531
16.4	Estimating the pH of Acid and Base Solutions	532
16.4a	Strong Acid and Strong Base Solutions	532
16.4b	Solutions Containing Weak Acids	533
16.4c	Solutions Containing Weak Bases	538
16.5	Acid–Base Properties of Salts	542
16.5a	Acid–Base Properties of Salts: Hydrolysis	542
16.5b	Determining pH of a Salt Solution	544
16.6	Molecular Structure and Control of Acid–Base Strength	546
16.6a	Molecular Structure and Control of Acid–Base Strength	546
	Unit Recap	549

17	Advanced Acid–Base Equilibria	553
17.1	Acid–Base Reactions	554
17.1a	Strong Acid/Strong Base Reactions	554
17.1b	Strong Acid/Weak Base and Strong Base/Weak Acid Reactions	555
17.1c	Weak Acid/Weak Base Reactions	557
17.2	Buffers	558
17.2a	Identifying Buffers	558
17.2b	Buffer pH	560
17.2c	Making Buffer Solutions	566
17.3	Acid–Base Titrations	571
17.3a	Strong Acid/Strong Base Titrations	571
17.3b	Weak Acid/Strong Base and Weak Base/Strong Acid Titrations	573
17.3c	pH Titration Plots as an Indicator of Acid or Base Strength	580
17.3d	pH Indicators	582
17.3e	Polyprotic Acid Titrations	584
17.4	Some Important Acid–Base Systems	587
17.4a	The Carbonate System: $\text{H}_2\text{CO}_3/\text{HCO}_3^-/\text{CO}_3^{2-}$	587
17.4b	Amino Acids	588
	Unit Recap	589

18	Precipitation and Lewis Acid–Base Equilibria	593
18.1	Solubility Equilibria and K_{sp}	594
18.1a	Solubility Units	594
18.1b	The Solubility Product Constant	595
18.1c	Determining K_{sp} Values	596
18.2	Using K_{sp} in Calculations	598
18.2a	Estimating Solubility	598
18.2b	Predicting Whether a Solid Will Precipitate or Dissolve	601
18.2c	The Common Ion Effect	603
18.3	Lewis Acid–Base Complexes and Complex Ion Equilibria	605
18.3a	Lewis Acids and Bases	605
18.3b	Complex Ion Equilibria	607
18.4	Simultaneous Equilibria	609
18.4a	Solubility and pH	609
18.4b	Solubility and Complex Ions	610
18.4c	Solubility, Ion Separation, and Qualitative Analysis	611
	Unit Recap	614

19 Thermodynamics: Entropy and Free Energy 617

19.1	Entropy and the Three Laws of Thermodynamics	618
19.1a	The First and Second Laws of Thermodynamics	618
19.1b	Entropy and the Second Law of Thermodynamics	619
19.1c	Entropy and Microstates	620
19.1d	Trends in Entropy	622
19.1e	Spontaneous Processes	624
19.1f	The Third Law of Thermodynamics and Standard Entropies	626
19.2	Calculating Entropy Change	628
19.2a	Standard Entropy Change for a Phase Change	628
19.2b	Standard Entropy Change for a Chemical Reaction	630
19.2c	Entropy Change in the Surroundings	631
19.3	Gibbs Free Energy	633
19.3a	Gibbs Free Energy and Spontaneity	633
19.3b	Standard Gibbs Free Energy	635
19.3c	Free Energy, Standard Free Energy, and the Reaction Quotient	637
19.3d	Standard Free Energy and the Equilibrium Constant	639
19.3e	Gibbs Free Energy and Temperature	642
	Unit Recap	646

20 Electrochemistry 651

20.1	Oxidation–Reduction Reactions and Electrochemical Cells	652
20.1a	Overview of Oxidation–Reduction Reactions	652
20.1b	Balancing Redox Reactions: Half-Reactions	654
20.1c	Balancing Redox Reactions in Acidic and Basic Solutions	657
20.1d	Construction and Components of Electrochemical Cells	660
20.1e	Electrochemical Cell Notation	663
20.2	Cell Potentials, Free Energy, and Equilibria	664
20.2a	Cell Potentials and Standard Reduction Potentials	664
20.2b	Cell Potential and Free Energy	671
20.2c	Cell Potential and the Equilibrium Constant	672
20.2d	Cell Potentials Under Nonstandard Conditions	674
20.2e	Concentration Cells	677
20.3	Electrolysis	678
20.3a	Electrolytic Cells and Coulometry	678
20.3b	Electrolysis of Molten Salts	681
20.3c	Electrolysis of Aqueous Solutions	684
20.4	Applications of Electrochemistry: Batteries and Corrosion	686
20.4a	Primary Batteries	686
20.4b	Secondary Batteries	687
20.4c	Fuel Cells	689
20.4d	Corrosion	690
	Unit Recap	692

21	Organic Chemistry	695
21.1	Hydrocarbons	696
21.1a	Classes of Hydrocarbons	696
21.1b	Alkanes and Cycloalkanes	698
21.1c	Unsaturated Hydrocarbons	701
21.1d	Hydrocarbon Reactivity	705
21.2	Isomerism	708
21.2a	Constitutional Isomerism	708
21.2b	Stereoisomerism	709
21.3	Functional Groups	711
21.3a	Identifying Functional Groups	711
21.3b	Alcohols	712
21.3c	Compounds Containing a Carbonyl Group	716
21.4	Synthetic Polymers	716
21.4a	Addition Polymerization	716
21.4b	Condensation Polymerization	717
21.4c	Control of Polymer Properties	720
21.5	Biopolymers	721
21.5a	Carbohydrates	721
21.5b	Amino Acids	725
21.5c	Proteins	726
21.5d	Nucleic Acids	728
	Unit Recap	731

22	Applying Chemical Principles to the Main-Group Elements	735
22.1	Structures of the Elements	736
22.1a	The Periodic Table	736
22.1b	Metals	737
22.1c	Nonmetals	739
22.2	Oxides and Halides of the Nonmetals	742
22.2a	Nonmetal Oxides	742
22.2b	Nonmetal Halides	744
22.3	Compounds of Boron and Carbon	745
22.3a	Boron Compounds	745
22.3b	Elemental Carbon	746
22.3c	Cave Chemistry	747
22.3d	Carbon Dioxide and Global Warming	748
22.4	Silicon	750
22.4a	Silicon Semiconductors	750
22.4b	Silicates	751
22.4c	Silicones	752
22.5	Oxygen and Sulfur in the Atmosphere	754
22.5a	Atmospheric Ozone	754
22.5b	Sulfur and Acid Rain	756
	Unit Recap	757

23	The Transition Metals	759
23.1	Properties of the Transition Metals	760
23.1a	General Characteristics of Transition Metals	760
23.1b	Atomic Size and Electronegativity	760
23.1c	Ionization Energy and Oxidation States	762
23.2	Isolation from Metal Ores	764
23.2a	Common Ores	764
23.2b	Extraction of Metals from Ores	764
23.3	Coordination Compounds: Structure and Isomerism	767
23.3a	Composition of Coordination Compounds	767
23.3b	Naming Coordination Compounds	770
23.3c	Stability and the Chelate Effect	773
23.3d	Isomerism	774
23.4	Coordination Compounds: Bonding and Spectroscopy	777
23.4a	Crystal Field Theory	777
23.4b	Molecular Orbital Theory	781
23.4c	Spectroscopy	784
	Unit Recap	786

24	Nuclear Chemistry	789
24.1	Nuclear Reactions	790
24.1a	Nuclear vs. Chemical Reactions	790
24.1b	Natural Radioactive Decay	791
24.1c	Radioactive Decay and Balancing Nuclear Reactions	792
24.2	Nuclear Stability	796
24.2a	Band of Stability	796
24.2b	Binding Energy	799
24.2c	Relative Binding Energy	801
24.3	Kinetics of Radioactive Decay	802
24.3a	Rate of Decay	802
24.3b	Radioactive Dating	804
24.4	Fission and Fusion	806
24.4a	Types of Fission Reactions	806
24.4b	Nuclear Fuel	808
24.4c	Nuclear Power	810
24.5	Applications and Uses of Nuclear Chemistry	812
24.5a	Stellar Synthesis of Elements	812
24.5b	Induced Synthesis of Elements	815
24.5c	Nuclear Medicine	817
24.5d	Radioactivity in the Home	818
	Unit Recap	820
	Reference Tables	823
	Glossary	837
	Index	850

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To the Student

Welcome to a new integrated approach to chemistry. Chemistry is a continually evolving science that examines and manipulates the world on the atomic and molecular level. In chemistry, it's mostly about the molecules. What are they like? What do they do? How can we make them? How do we even know if we have made them? One of the primary goals of chemistry is to understand matter on the molecular scale well enough to allow us to predict which chemical structures will yield particular properties, and the insight to be able to synthesize those structures.

In this first-year course you will learn about atoms and how they form molecules and other larger structures. You will use molecular structure and the ways atoms bond together to explain the chemical and physical properties of matter on the molecular and bulk scales, and in many cases you will learn to predict these behaviors. One of the most challenging and rewarding aspects of chemistry is that we describe and predict bulk, human scale properties through an understanding of particles that are so very tiny they cannot be seen even with the most powerful optical microscope. So, when we see things happen in the world, we translate and imagine what must be occurring to the molecules that we can't ever see.

Our integrated approach is designed to be one vehicle in your learning; it represents a new kind of learning environment built by making the best

uses of traditional written explanations, with interactive activities to help you learn the central concepts of chemistry and how to use those concepts to solve a wide variety of useful and chemically important problems. These readings and activities will represent your homework and as such you will find that your book is your homework, and your homework is your book. In this regard, the interactive reading assignments contain integrated active versions of important figures and tables, reading comprehension questions, and suites of problem solving examples that give you step-by-step tutorial help, recorded "video solutions" to important problems, and practice problems with rich feedback that allow you to practice a problem type multiple times using different chemical examples. In addition to the interactive reading assignments, there are additional OWL problems designed to solidify your understanding of each section as well as end-of-chapter assignments.

The authors of the OWLBook have decades of experience teaching chemistry, talking with students, and developing online chemistry learning systems. For us, this work represents our latest effort to help students beyond our own classrooms and colleges. All in all, we hope that your time with us is rewarding and we wish you the best of luck.

1

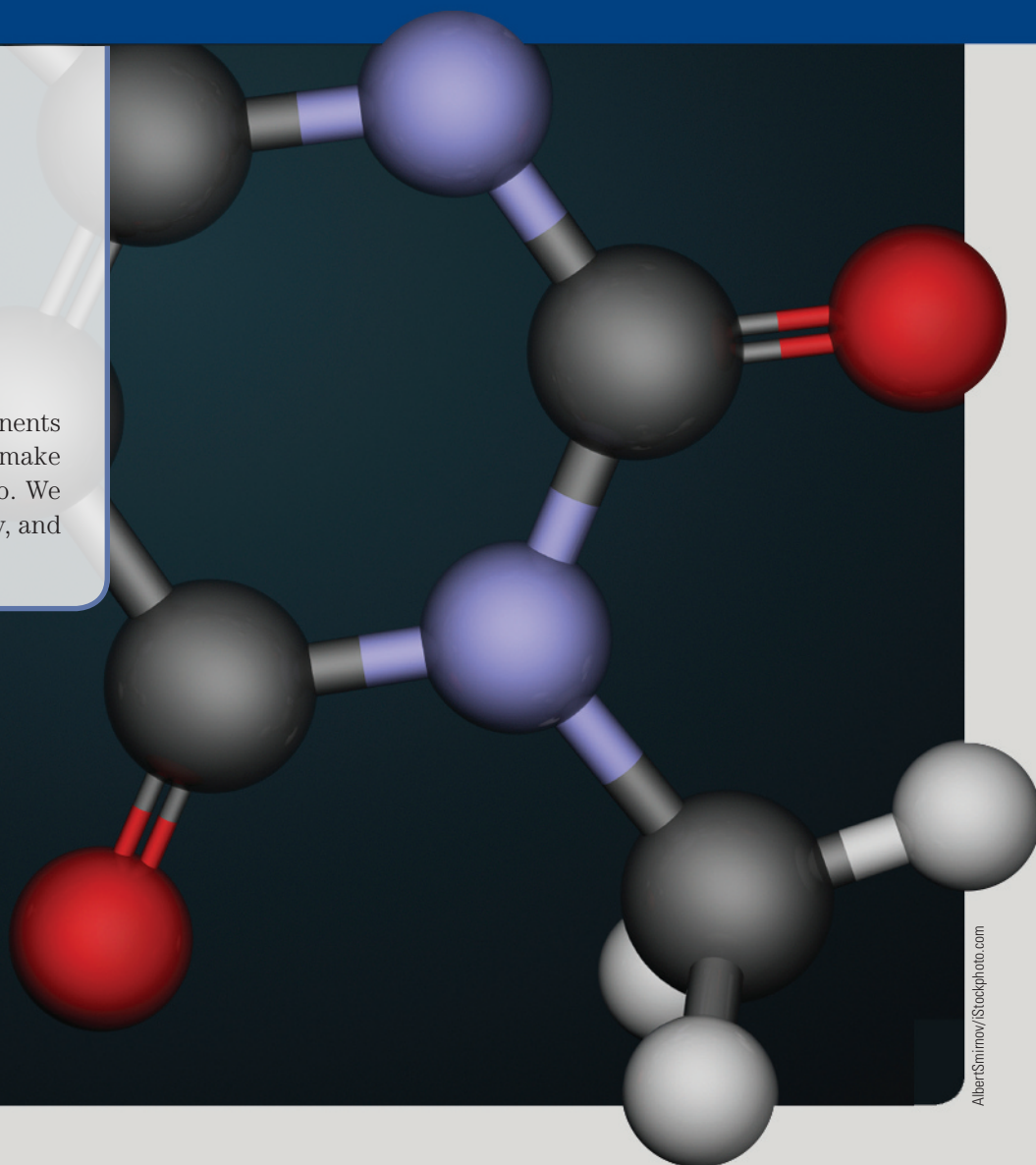
Chemistry: Matter on the Atomic Scale

Unit Outline

- 1.1 What Is Chemistry?
- 1.2 Classification of Matter
- 1.3 Units and Measurement
- 1.4 Unit Conversions

In This Unit...

This unit introduces atoms and molecules, the fundamental components of matter, along with the different types of structures they can make when they join together, and the types of changes they undergo. We also describe some of the tools scientists use to describe, classify, and measure matter.



1.1 What Is Chemistry?

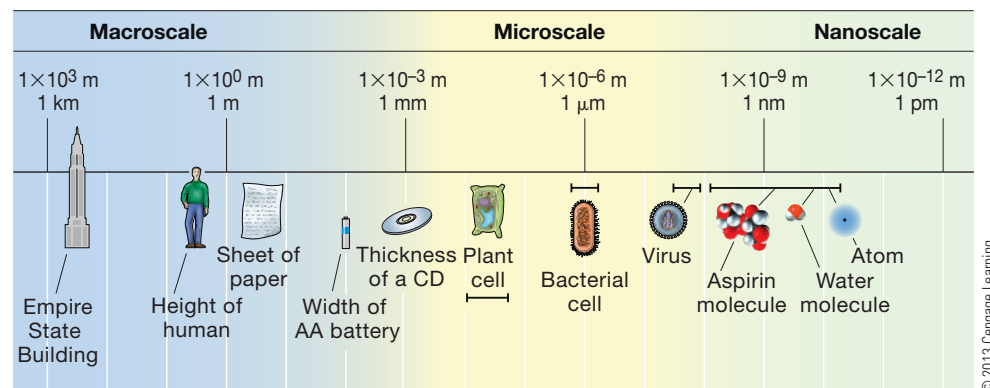
1.1a The Scale of Chemistry

Chemistry is the study of matter, its transformations, and how it behaves. We define **matter** as any physical substance that occupies space and has mass. Matter consists of atoms and molecules, and it is at the atomic and molecular level that chemical transformations take place.

Different fields of science examine the world at different levels of detail (Interactive Figure 1.1.1). When describing matter that can be seen with the naked eye, scientists are working on the **macroscopic scale**. Chemists use the **atomic scale** (sometimes called the *nanoscale* or the *molecular scale*) when describing individual atoms or molecules. In general, in chemistry we make observations at the macroscopic level and we describe and explain chemical processes on the atomic level. That is, we use our macroscopic scale observations to explain atomic scale properties.

Interactive Figure 1.1.1

Understand the scale of science.



The macroscopic, microscopic, and atomic scales in different fields of science.

1.1b Measuring Matter

Chemistry is an experimental science that involves designing thoughtful experiments and making careful observations of macroscopic amounts of matter. Everything that is known about how atoms and molecules interact has been learned through making careful

observations on the macroscopic scale and inferring what those observations must mean about atomic scale objects.

For example, careful measurement of the mass of a chemical sample before and after it is heated provides information about the chemical composition of a substance. Observing how a chemical sample behaves in the presence of a strong magnetic field such as that found in a magnetic resonance imaging (MRI) scanner provides information about how molecules and atoms are arranged in human tissues.

An important part of chemistry and science in general is the concept that all ideas are open to challenge. When we perform measurements on chemical substances and interpret the results in terms of atomic scale properties, the results are always examined to see if there are alternative ways to interpret the data. This method of investigation leads to chemical information about the properties and behavior of matter that is supported by the results of many different experiments.

Example Problem 1.1.1 Differentiate between the macroscopic and atomic scales.

Classify each of the following as matter that can be measured or observed on either the macroscopic or atomic scale.

- An RNA molecule
- A mercury atom
- A sample of liquid mercury

Solution:

You are asked to identify whether a substance can be measured or observed on the macroscopic or atomic scales.

You are given the identity of the substance.

- Atomic scale. An RNA molecule is too small to be seen with the naked eye or with an optical microscope.
- Atomic scale. Individual atoms cannot be seen with the naked eye or with an optical microscope.
- Macroscopic scale. Liquid mercury can be seen with the naked eye.

Video Solution

Tutored Practice
Problem 1.1.1

Section 1.1 Mastery

1.2 Classification of Matter

1.2a Classifying Matter on the Atomic Scale

Matter can be described by a collection of characteristics called **properties**. One of the fundamental properties of matter is its composition, or the specific types of atoms or molecules that make it up. An **element**, which is the simplest type of matter, is a pure

substance that cannot be broken down or separated into simpler substances. (►Flashforward to Section 2.2 Elements and the Periodic Table) You are already familiar with some of the most common elements such as gold, silver, and copper, which are used in making coins and jewelry, and oxygen, nitrogen, and argon, which are the three most abundant gases in our atmosphere. A total of 118 elements have been identified, 90 of which exist in nature (the rest have been synthesized in the laboratory). Elements are represented by a one- or two-letter element symbol, and they are organized in the periodic table that is shown in Elements and Compounds (Unit 2) and in the Reference Tools. A few common elements and their symbols are shown in Table 1.1.1. Notice that when the symbol for an element consists of two letters, only the first letter is capitalized.

Atoms

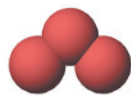
An **atom** is the smallest indivisible unit of an element. For example, the element aluminum (Interactive Figure 1.2.1) is made up entirely of aluminum atoms. Although individual atoms are too small to be seen directly with the naked eye or with the use of a standard microscope, methods such as scanning tunneling microscopy (STM) allow scientists to view atoms. Both experimental observations and theoretical studies show that isolated atoms are spherical and that atoms of different elements have different sizes. Thus, the model used to represent isolated atoms consists of spheres of different sizes. In addition, chemists often use color to distinguish atoms of different elements. For example, oxygen atoms are usually represented as red spheres; carbon atoms, as gray or black spheres; and hydrogen atoms, as white spheres.

Elements are made up of only one type of atom. For example, the element oxygen is found in two forms: as O_2 , in which two oxygen atoms are grouped together, and as O_3 , in which three oxygen atoms are grouped together. The most common form of oxygen is

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Dioxygen, O_2



Ozone, O_3

O_2 , dioxygen, a gas that makes up about 21% of the air we breathe. Ozone, O_3 , is a gas with a distinct odor that can be toxic to humans. Both dioxygen and ozone are elemental forms of oxygen because they consist of only one type of atom.

Table 1.1.1 Some Common Elements and Their Symbols

Name	Symbol
Hydrogen	H
Carbon	C
Oxygen	O
Sodium	Na
Iron	Fe
Aluminum	Al

Interactive Figure 1.2.1

Explore the composition of elements.

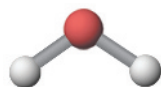


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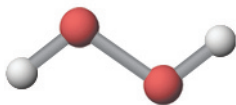
A piece of aluminum

Compounds and Molecules

A **chemical compound** is a substance formed when two or more elements are combined in a defined ratio. Compounds differ from elements in that they can be broken down chemically into simpler substances. You have encountered chemical compounds in many common substances, such as table salt, a compound consisting of the elements sodium and chlorine, and phosphoric acid, a compound found in soft drinks that contains hydrogen, oxygen, and phosphorus.



Water, H₂O



Hydrogen peroxide, H₂O₂

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Molecules are collections of atoms that are held together by chemical bonds. In models used to represent molecules, chemical bonds are often represented using cylinders or lines that connect atoms, represented as spheres. The composition and arrangement of elements in molecules affects the properties of a substance. For example, molecules of both water (H₂O) and hydrogen peroxide (H₂O₂) contain only the elements hydrogen and oxygen. Water is a relatively inert substance that is safe to drink in its pure form. Hydrogen peroxide, however, is a reactive liquid that is used to disinfect wounds and can cause severe burns if swallowed.

Example Problem 1.2.1 Classify pure substances as elements or compounds.

Classify each of the following substances as either an element or a compound.

- a. Si b. CO₂ c. P₄

Solution:

You are asked to classify a substance as an element or a compound.

You are given the chemical formula of the substance.

- Element. Silicon is an example of an element because it consists of only one type of atom.
- Compound. This compound contains both carbon and oxygen.
- Element. Although this is an example of a molecular substance, it consists of only a single type of atom.

Video Solution

Tutored Practice
Problem 1.2.1

1.2b Classifying Pure Substances on the Macroscopic Scale

A **pure substance** contains only one type of element or compound and has fixed chemical composition. A pure substance also has characteristic properties, measurable qualities that are independent of the sample size. The **physical properties** of a chemical substance are those that do not change the chemical composition of the material when they are measured.

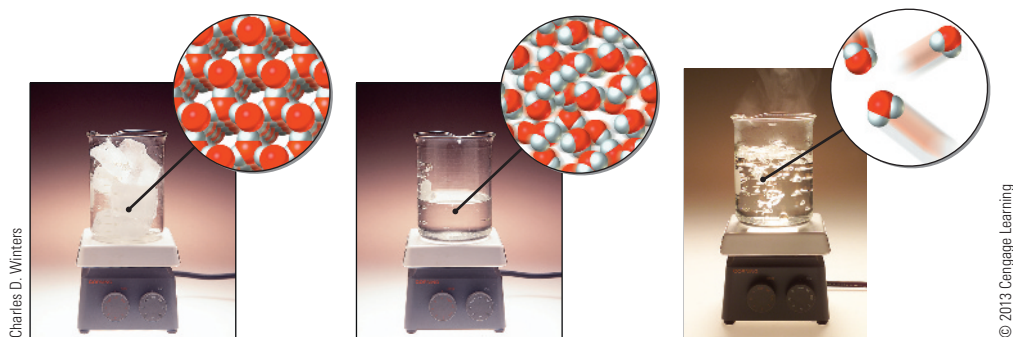
Some examples of physical properties include physical state, color, viscosity (resistance to flow), opacity, density, conductivity, and melting and boiling points.

States of Matter

One of the most important physical properties is the physical state of a material. The three physical **states of matter** are solid, liquid, and gas (Interactive Figure 1.2.2).

Interactive Figure 1.2.2

Distinguish the properties of the three states of matter.



Representations of a solid, a liquid, and a gas

The macroscopic properties of these states are directly related to the arrangement and properties of particles at the atomic level. At the macroscopic level, a **solid** is a dense material with a defined shape. At the atomic level, the atoms or molecules of a solid are packed together closely. The atoms or molecules are vibrating, but they do not move past one another. At the macroscopic level, a **liquid** is also dense, but unlike a solid it flows and takes on the shape of its container. At the atomic level, the atoms or molecules of a liquid are close together, but they move more than the particles in a solid and can flow past one another. Finally, at the macroscopic level, a **gas** has no fixed shape or volume. At the atomic level, the atoms or molecules of a gas are spaced widely apart and are moving rapidly past one another. The particles of a gas do not strongly interact with one another, and they move freely until they collide with one another or with the walls of the container.

The physical state of a substance can change when energy, often in the form of heat, is added or removed. When energy is added to a solid, the temperature at which the solid is converted to a liquid is the **melting point** of the substance. The conversion of liquid to solid occurs at the same temperature as energy is removed (the temperature falls) and is called the **freezing point**. A liquid is converted to a gas at the **boiling point** of a substance. As you

will see in the following section, melting and boiling points are measured in Celsius ($^{\circ}\text{C}$) or Kelvin (K) temperature units.

Not all materials can exist in all three physical states. Polyethylene, for example, does not exist as a gas. Heating a solid polyethylene milk bottle at high temperatures causes it to decompose into other substances. Helium, a gas at room temperature, can be liquefied at very low temperatures, but it is not possible to solidify helium.

A change in the physical property of a substance is called a **physical change**. Physical changes may change the appearance or the physical state of a substance, but they do not change its chemical composition. For example, a change in the physical state of water—changing from a liquid to a gas—involves a change in how the particles are packed together at the atomic level, but it does not change the chemical makeup of the material.

Chemical Properties

The **chemical properties** of a substance are those that involve a chemical change in the material and often involve a substance interacting with other chemicals. For example, a chemical property of methanol, CH_3OH , is that it is highly flammable because the compound burns in air (it reacts with oxygen in the air) to form water and carbon dioxide (Interactive Figure 1.2.3). A **chemical change** involves a change in the chemical composition of the material. The flammability of methanol is a chemical property, and demonstrating this chemical property involves a chemical change.

Example Problem 1.2.2 Identify physical and chemical properties and physical and chemical changes.

- When aluminum foil is placed into liquid bromine a white solid forms. Is this a chemical or physical property of aluminum?
- Iodine is a purple solid. Is this a chemical or physical property of iodine?
- Classify each of the following changes as chemical or physical.
 - Boiling water
 - Baking bread

Solution:

You are asked to identify a change or property as chemical or physical.

You are given a description of a material or a change.

- Chemical property. Chemical properties are those that involve a chemical change in the material and often involve a substance interacting with other chemicals. In this example, one substance (the aluminum) is converted into a new substance (a white solid).

Interactive Figure 1.2.3

Investigate the chemical properties of methanol.



Charles D. Winters

Methanol is a flammable liquid.

Video Solution

Tutored Practice
Problem 1.2.2

Example Problem 1.2.2 (continued)

- b. Physical property. A physical property such as color is observed without changing the chemical identity of the substance.
- c. i. Physical change. A physical change alters the physical form of a substance without changing its chemical identity. Boiling does not change the chemical composition of water.
- ii. Chemical change. When a chemical change takes place, the original substances (the bread ingredients) are broken down and a new substance (bread) is formed.

1.2c Classifying Mixtures on the Macroscopic Scale

As you can see when you look around you, the world is made of complex materials. Much of what surrounds us is made up of mixtures of different substances. A **mixture** is a substance made up of two or more elements or compounds that have not reacted chemically.

Unlike compounds, where the ratio of elements is fixed, the relative amounts of different components in a mixture can vary. Mixtures that have a constant composition throughout the material are called **homogeneous mixtures**. For example, dissolving table salt in water creates a mixture of the two chemical compounds water (H_2O) and table salt (NaCl). Because the mixture is uniform, meaning that the same ratio of water to table salt is found no matter where it is sampled, it is a homogeneous mixture.

A mixture in which the composition is not uniform is called a **heterogeneous mixture**. For example, a cold glass of freshly squeezed lemonade with ice is a heterogeneous mixture because you can see the individual components (ice cubes, lemonade, and pulp) and the relative amounts of each component will depend on where the lemonade is sampled (from the top of the glass or from the bottom). The two different types of mixtures are explored in Interactive Figure 1.2.4.

Homogeneous and heterogeneous mixtures can usually be physically separated into individual components. For example, a homogeneous mixture of salt and water is separated by heating the mixture to evaporate the water, leaving behind the salt. A heterogeneous mixture of sand and water is separated by pouring the mixture through filter paper. The sand is trapped in the filter while the water passes through. Heating the wet sand to evaporate the remaining water completes the physical separation.

Like pure substances, mixtures have physical and chemical properties. These properties, however, depend on the composition of the mixture. For example, a mixture of 10 grams of table sugar and 100 grams of water has a boiling point of 100.15°C while a mixture of 20 grams of table sugar and 100 grams of water has a boiling point of 100.30°C .

Interactive Figure 1.2.5 summarizes how we classify different forms of matter in chemistry.

Interactive Figure 1.2.4

Identify homogeneous and heterogeneous mixtures.

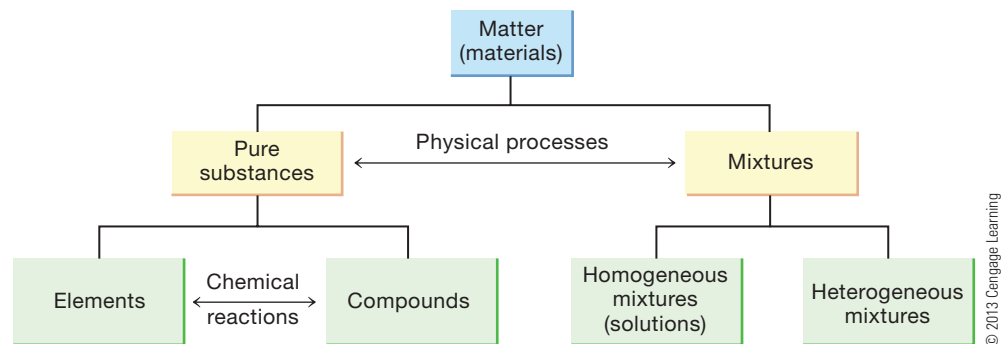


Homogeneous and heterogeneous mixtures

Charles D. Winters

Interactive Figure 1.2.5

Classify matter.



A flow chart for the classification of matter

Example Problem 1.2.3 Identify pure substances and mixtures.

Classify each of the following as a pure substance, a homogeneous mixture, or a heterogeneous mixture.

- Copper wire
- Oil and vinegar salad dressing
- Vinegar

Solution:

You are asked to classify items as a pure substance, a heterogeneous mixture, or a homogeneous mixture.

You are given the identity of the item.

- Pure substance. Copper is an element.
- Heterogeneous mixture. The salad dressing is a mixture that does not have a uniform composition. The different components are visible to the naked eye, and the composition of the mixture varies with the sampling location.
- Homogeneous mixture. Vinegar is a uniform mixture of water, acetic acid, and other compounds. The different components in this mixture are not visible to the naked eye.

Video Solution

Tutored Practice
Problem 1.2.3

Section 1.2 Mastery